Chapter 6

Importance of Ecological Diversity in Maintaining Long-Term Site Productivity

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ABSTRACT

Long-term site productivity is ultimately dependent upon ecosystem resilience—an ability to absorb stress or change without significant loss of function—and not simply soil properties. Forest ecosystems are faced with dramatic changes in climate, pollutants, and pests and pathogens. These uncertainties, coupled with our demonstrably inadequate knowledge of ecosystem function, strongly indicate management approaches which retain the genetic, structural, landscape, and temporal diversity critical to resilience. Current management emphases simplify forests. Alternative management programs that retain diversity, including schemes which accommodate early successional species, provide for coarse, woody debris, create mixed stands, protect streamside habitats, and provide for diverse and functional landscapes, are suggested. Foresters must manage to retain greater ecological margins in order to sustain long-term productivity and buffer against uncertainties.

INTRODUCTION

Scientists and land managers tend to focus primarily on soil nutrients when considering the issue of long-term site productivity. But long-term site productivity extends beyond plant nutrition to soil physical properties and the biotic contribution to both chemical and physical properties. The importance of woody organic matter incorporated into the soil (Harvey et al. 1979) and of roots as pumps and points of energy ("white holes") in the soil matrix are good examples (Perry et al. 1987).

Long-term site productivity goes far beyond soil considerations, however, to the larger issue of maintaining resilience in forest ecosystems and landscapes. By "resilience" we mean an ecosystem's ability to absorb stress or change without significant loss of function. It is this ability which must be the concern of resource managers.

In this chapter, we address the changes and stresses to which forest ecosystems currently are subjected; reexamine simplification of forest ecosystems, which has been our traditional management approach; and propose altering practices to assure ecosystem resilience, in the face of stresses and the uncertainty they bring, through maintaining diversity and complexity in our forests to keep all future options open. Our concern extends to a forest's ability to sustain production of a complete array of goods and services, from wood fiber to wildlife habitat. We focus primarily upon forest growth or production, however, in the belief that by maintaining a site's capacity for photosynthetically converting the sun's energy to the complex organic structures known as trees, we retain the potential to create any specific set of forest goods and services. If we reduce a sites's potential to convert energy to trees then we have limited society's options.

CHANGE AND STRESS IN OUR FOREST ENVIRONMENTS

We relatively short-lived humans tend to view forests and soils as essentially eternal in their current form. Indeed, it is difficult for us to imagine these ecosystems in other conditions or to sense gradual or subtle changes in their character. But forests and forest environments are not immutable. There are many profound examples of current, ongoing changes.

Global Climatic Change

Increased levels of carbon dioxide, methane, and other trace gases are producing global climatic changes through the "greenhouse effect," whereby more of the sun's radiant energy is trapped in the atmosphere. A 4–5°C increase in mean temperature is predicted for the Pacific Northwest during the next 30–40 years, along with perhaps a slight decrease in summer precipitation (Schneider 1989). This change in climate is equivalent to an upward 1,000-m change in elevation—that is, the climate currently found at 1,000 m elevation on a mountain slope would occur at 2,000 m elevation (Franklin et al. 1989). The net effect, on site, will be increased droughtiness as the effective moisture declines.

Certain major impacts on northwestern forests due to climatic change seem likely (Franklin et al. 1989), although some (e.g., Woodman 1987) suggest that it will have little consequence. For example, environmental changes could profoundly alter the present match of species and their genetic strains with site. Leverenz and Lev (1987) have discussed effects on species ranges based upon physiological factors. If major shifts in species dominance seem far-fetched, we need only note that Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] has been a major species in this region only during this interglacial period and a dominant for only about 7,000 years (Brubaker 1988); other currently dominant species, such as ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), have similar histories. Profound changes have taken place in northwestern vegetation in response to past fluctuations in climate which were much smaller than those projected for the next 40 years; for example, the maximum temperatures experienced during this interglacial period were only 2° warmer than those at present (Brubaker 1986), yet lowland areas of the Pacific Northwest were apparently more sparsely forested than at present.

Perhaps the most profound effects of global climatic change will be on disturbance regimes—frequency, intensity, scale, and locale of wildfire, wind and rain storms, and outbreaks of pests and pathogens. In some cases, altered disturbance regimes will create a "double whammy," as the existing forests are destroyed and hotter, drier conditions make tree regeneration even more difficult (Franklin et al. 1989).

Pollutants

Pollutant loadings of all types, including photooxidants, ozone, acid precipitation, and heavy metals, are increasing dramatically. Moreover, such pollutants typically behave in concert (synergistically), further accentuating their impact on productivity. Although pollution problems in forested areas are more acute in the eastern United States, central and southern California, and Europe, levels of various chemical pollutants are also increasing in parts of the Pacific Northwest, and the potential for serious problems exists (e.g., Sun 1985).

Air pollutants stress forests in various ways depending upon their intensity and type (Kozlowski and Constantinidou 1986). Reduced growth, reduced reproduction, and increased mortality due either to increased susceptibility to pests or pathogens or to direct induction of disease are typical at intermediate pollutant dosages. Highly elevated levels of mortality and complete elimination of species may result from high dosages. Tree species do vary substantially in their susceptibility to air pollutants—with conifers generally more susceptible than hardwoods.

Pests and Pathogens

Human society is dramatically altering the pest and pathogen loads on forests by introducing new pests, making forest communities more vulnerable by altering their structure and composition, and increasing physiological stresses (e.g., through global climatic change). Conversion of old-growth to younger stands was once thought to be a key in reducing losses to pests and pathogens; this conversion has instead brought other problems, such as the necessity to deal with infection centers of *Phellinus weirii* root rot (Childs 1970).

Shigo (1985) has commented that disease problems appear to be much more serious in managed than in natural stands. For example, monocultures (stands of single species) of southern pines, especially planted monocultures of the most susceptible species, create conditions for immense and unimpeded outbreaks of the southern pine bark beetle (*Dendroctonus frontalis*) (Schowalter 1986). Frequent management entries may be detrimental in themselves by, for instance, facilitating spread of damaging root rots. We find that silvicultural practices as common as thinning can create major problems. Thinning can increase the occurrence of root rots such as *Fomes annosus* (Ross 1973). As another example, precommercial thinning of Douglas-fir can dramatically increase levels of the Douglas-fir root bark beetle (*Hylastes nigrinus*) (Fig. 6.1), which is the vector for black stain fungus (*Ceratocystis wageneri*) (Witcosky et al. 1986). Young Douglas-fir plantations are also more seriously affected by foliage diseases. Moreover, damage by herbivorous insects may increase in importance as the old-growth component of forests is lost. Old-growth stands are a net source of insect predators (Table 6.1) and also hamper the progress of herbivorous host-seeking insects which must pass through areas of unfavorable vegetation in search of desirable young trees (Schowalter 1989).

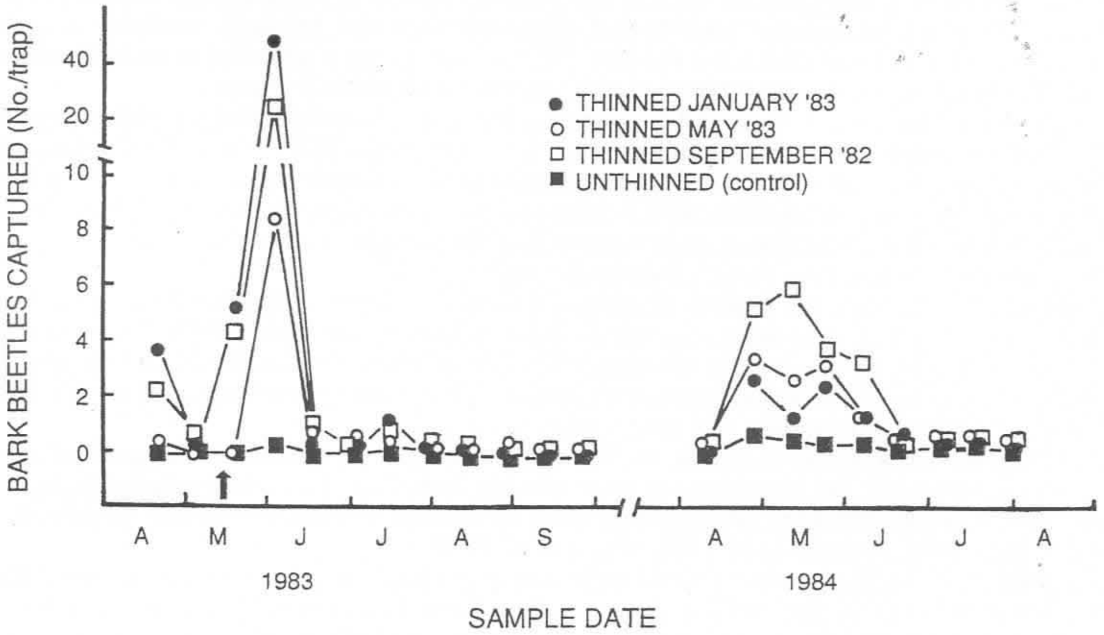

FIG. 6.1. Occurrence of Douglas-fir root bark beetle, the vector for black stain fungus, for 2 years following precommercial thinning in a 20-year-old Douglas-fir stand; thinning greatly elevated levels of beetles over those encountered in the unthinned control (adapted from Witcosky et al. 1986).

TABLE 6.1. Mean arthropod densities in a young (10-year-old) Douglas-fir and old-growth (450-year-old) Douglas fir-western hemlock stand. Numbers of species are in parentheses. One interpretation of these data is that greater plant and arthropod diversity of old-growth forests limits pest populations; old-growth forest have over 100 times as many predators as young forests (adapted from Schowalter 1989).

Arthropod type	*Young Douglas-fir*	*Old-growth Douglas-fir*	*Old-growth hemlock*
		No. of individuals/kg	
Folivores			
Gall aphids	29,000 (1)	48 (1)	28 (1)
Aphids	100 (1)	0	0
Scale insects	2 (1)	49 (2)	110 (3)
Budmoths	0	1 (7)	0
Other folivores	2 (2)	1 (7)	2 (5)
Pollen and seed feeders			
Seed bugs	0	1 (1)	12 (3)
Thrips	0	3 (2)	1 (2)
Detritivores			
Oribatid mites	0	17 (5)	50 (5)
Insects	0	1 (4)	12 (4)
Predators			
Ants	2 (1)	1 (2)	0
Aphid predators	9 (1)	3 (5)	1 (4)
Parasitic wasps	8 (4)	2 (5)	1 (4)
Other insects	3 (2)	2 (3)	0
Spiders	19 (3)	14 (15)	15 (15)
Other arachnids	0	5 (2)	7 (2)
		Predators: folivore	
	0.0014	0.26	0.18

INADEQUATE INFORMATION AND HUMILITY

Along with change and the uncertainty that it brings, our woefully inadequate knowledge of forest ecosystems should humble us. The last 2 decades have brought important discoveries with many surprises, including the following basic findings:

(1) The importance of photosynthesis outside the growing season in northwestern forests (Waring and Franklin 1979). We previously believed that photosynthesis was primarily confined to spring and summer, but we now know that is not the case. This knowledge has allowed us to understand how mild winter climates give conifers an advantage over deciduous hardwood species;

(2) The high rate of turnover of roots and mycorrhizae in forest ecosystems and the high energy requirements for their maintenance—requirements often far out of proportion to the 20% of biomass typically found belowground. In one subalpine (high-elevation) forest, 73% of the net primary productivity went to belowground dry-matter production, 66% to fine roots and mycorrhizae (Grier et al. 1981). One implication of this finding is that fertilization and irrigation may simply shift production from below the ground to above it without altering total forest productivity; and

(3) The numerous pathways for fixation (conversion to usable form) and loss of biologically available nitrogen, including microbial fixation in woody debris (Cornaby and Waide 1973, Sharpe and Milbank 1973) and fixation by canopy lichens (Denison 1979, Carroll 1980). Previously, all sources of biologically available nitrogen had been largely unknown in forests. These findings have provided us with opportunities to increase nitrogen fixation, and thus fertility, in forests.

Recognizing the importance of coarse, woody debris has been a particularly conspicuous reversal in resource managers' thinking. We have matured from viewing such materials as fire hazards, physical impediments, and waste (Cramer 1974) to understanding them as essential structures in forests, streams, and rivers (Maser and Trappe 1984, Harmon et al. 1986, Maser et al. 1988).

We have just now entered a period of rapid expansion in our knowledge of forest ecosystems. Already we are learning that parts of forests that we have never considered seriously are proving significant, even essential, to ecosystem functioning. And through this new information, we are finally recognizing the many fallacies and weaknesses in our traditional forestry dogma. In pursuit of high, short-term returns we have attempted to mimick intensive agriculture, which moves us toward a homogenized, simplified forest, one requiring large energy subsidies. Simultaneously, we have been wondering how far the system can be pushed and rationalizing with "don't worry too much—we can fix it later." But can we? Considering the uncertainties of the future and our still inadequate knowledge base, we must ask ourselves: have we been proceeding prudently? The answer, inescapably, is no.

SIMPLIFICATION—THE TRADITIONAL EMPHASIS

Forest ecosystems may be homogenized or simplified at several levels: genetic, structural (the stand: small spatial scale), landscape (larger spatial scale), and temporal (successional).

Genetic simplification takes many forms, including elimination or exclusion of some species and reduction of genetic variability in others. Elimination and exclusion usually occur by accident rather than by design, as when certain animal species associated with old-growth forests are lost because the old-growth component is eliminated from a landscape. Reduced genetic variability within species is often by design, through programs of genetic improvement or, even more drastically, programs for cloning commercial tree species. Other forestry activities, such as artificial regeneration of trees from wild seed, can result in substantial, unplanned modification of their natural genetic variability even when the seed is from the same area because the seedlings undergo very different selection processes in a nursery than in the wild. Creating uniform stands with a narrowed genetic base increases the vulnerability of forests to changes in climate, pollutants, and pests and pathogens.

More generally, excessive promotion of dense populations of any host-tree species, even without a narrowed genetic base, can be expected to lead to outbreaks and other pest-management problems. Most pests and pathogens have narrow host ranges including one or a few congeneric plant species; even polyphagous insects such as the gypsy moth (*Lymantria dispar* L.) accept as hosts plants from only a few temperate families (Daterman et al. 1986, Schowalter 1986). Many pests focus on specific genotypes (e.g., Alstad and Edmonds 1983, Perry and Pitman 1983, Whitham 1983). Most hosts also have specific ages during which they are vulnerable (Schowalter et al. 1986). Hence, reducing the distance, in time or space, between suitable host trees increases the likelihood that the pest will "discover" and propagate rapidly through the host. Simplifying stand composition or forest age structures creates high host density in space and time, reducing natural barriers. Conversely, potential pests are limited naturally in diverse ecosystems by the high cost (in terms of time and energy) of locating suitable resources in a structurally complex matrix of hosts and nonhosts (Kareiva 1983, Schultz 1983, Courtney 1986, Schowalter et al. 1986).

Structural simplification within forests includes eliminating dead trees and downed logs, reducing the range of tree sizes and growth forms, and using geometrical tree spacings. Long before intensive forest management was initiated, foresters removed dead wood because of concerns over wildfire. Practices such as YUM (yarding unmerchantable material) and PUM (piling unmerchantable material) are the ultimate result of such efforts (Cramer 1974). Fortunately, major changes in these practices are underway because the structural diversity afforded by this "unmerchantable material" (i.e., woody debris) can yield numerous ecological benefits. For example, retention or re-creation of structural diversity can significantly enhance biological diversity by providing a greater array of habitat (and, often, higher quality habitat) for plant and vertebrate and invertebrate animal species. As another example, coarse woody debris contributes to long-term site productivity by providing organic matter.

Landscape modifications have been mixed in their effects. Management practices have most often increased the number of discrete patches of forest (Fig. 6.2) but have reduced the range of patch sizes, homogenized conditions within the patches, and increased, sharpened, and straightened boundaries between patches. Such activities can have some benefits, such as creating large amounts of habitat for wildlife species that live at the forest edge. On the other hand, landscape manipulations have sometimes produced patches which are too small to provide suitable conditions for species requiring interior habitat, and extensive areas of forest edge can contribute significantly to accelerated tree mortality in residual stands (Franklin and Forman 1987).

Temporal simplification results when the length of early successional stages is shortened and late successional stages are eliminated (Fig. 6.3). An intensive forestry goal is usually rapid reestablishment of a fully stocked, closed-canopy forest. However, tree planting and control of competing vegetation—practices intended to achieve this goal—in turn can drastically shorten the period of herb and shrub dominance which precedes closure of the tree canopy. Federal forest lands generally are harvested at "culmination of mean annual increment," or the time when cumulative tree productivity is maximized: this is the transition from young (up to 80–100 year old) to mature (100–200 year old) forest. Hence, both the mature and old-growth (greater than 200-year-old) forest stages are eliminated under intensive forest management.

In general, we have tended to forget that what is good for wood production is not necessarily good for other organisms or processes in a forest ecosystem. Fully stocked young forests, the forester's ideal, are the most simplified stage of forest development in terms of structure and function, and the most impoverished in terms of biological diversity. Essentially all of the site resources are co-opted by the rapidly growing young trees.

Although some simplification is essential, much of it is not. Indeed, simplification—genetic, structural, landscape, and temporal—reduces ecosystem resilience, eliminating redundancies that could be important in saving the ecosystem, and us. Because the ability of an ecosystem to tolerate or absorb new kinds of stresses or changes is clearly of increasing consequence, the key to retaining resilience must be in maintaining ecological complexity or diversity. Thus we see that a sustainable forestry is in fact supported by three legs: ecological diversity, genetic diversity, and soils (Fig. 6.4).

It may be useful to think about forest ecosystems in the same way that we think about our personal health or finances. If we utilize such resources to their limits (or, perhaps, even borrow a little on our future), we have no reserves to draw on when subjected to an unexpected stress. Similarly, if we push our forest ecosystems (or most other natural resources) to their limits—maximum sustainable yield—little reserve will be available for the unforeseen contingencies that are the inevitable by-products of change.

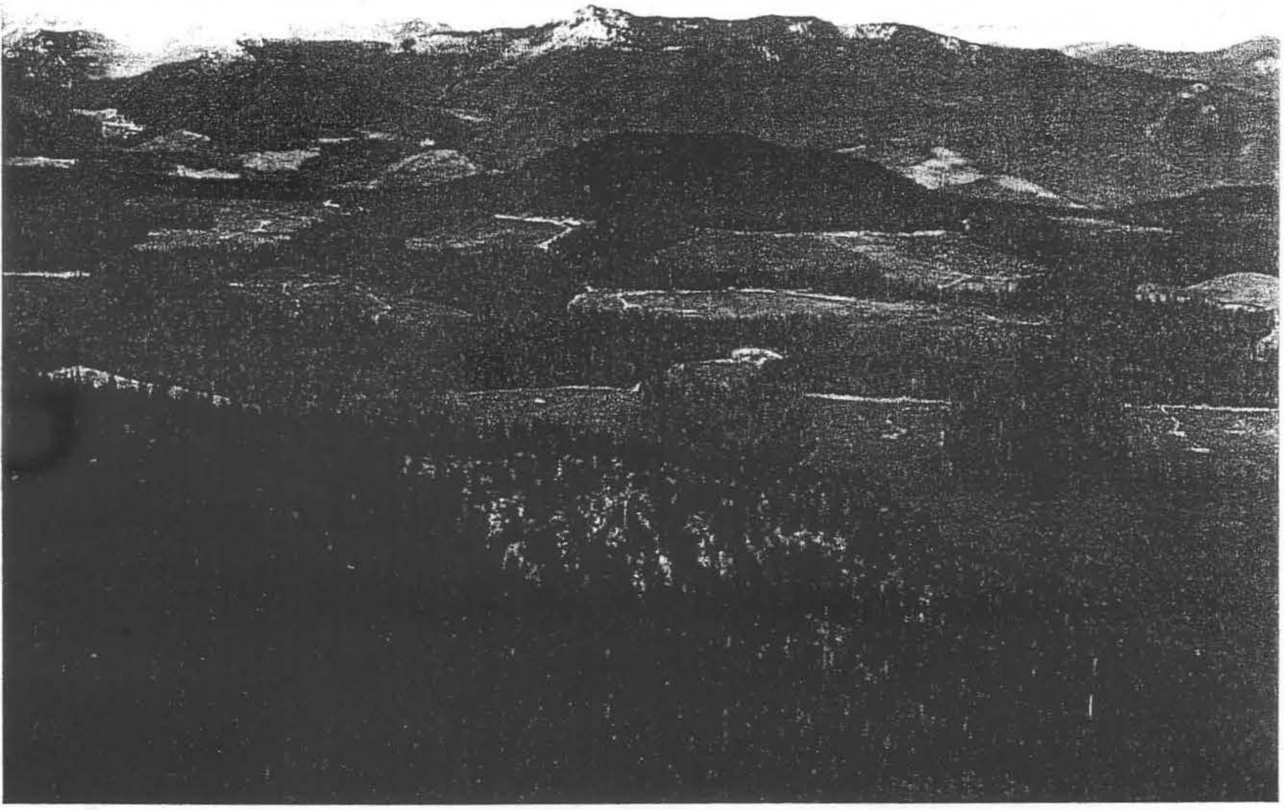

FIG. 6.2. Dispersed patch clearcutting on National Forest lands in the Douglas-fir Region has typically increased the number of discrete patches of forest but reduced the range of patch sizes and drastically increased, straightened, and sharpened boundaries between patches.

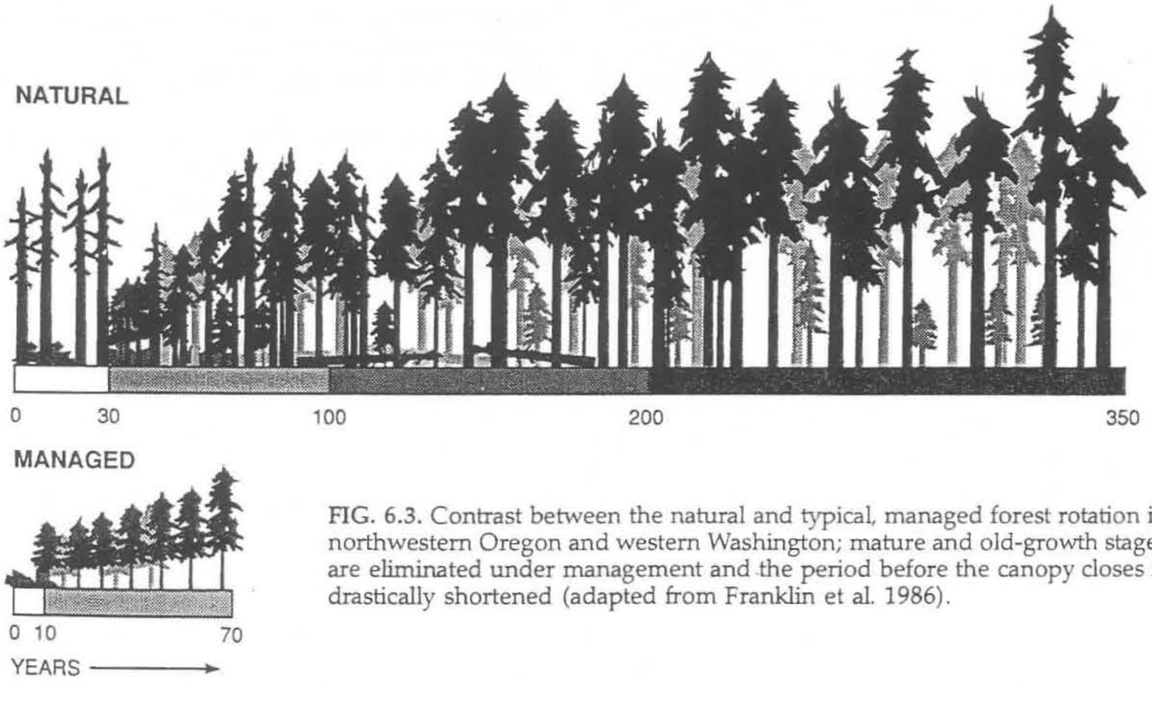

FIG. 6.3. Contrast between the natural and typical, managed forest rotation in northwestern Oregon and western Washington; mature and old-growth stages are eliminated under management and the period before the canopy closes is drastically shortened (adapted from Franklin et al. 1986).

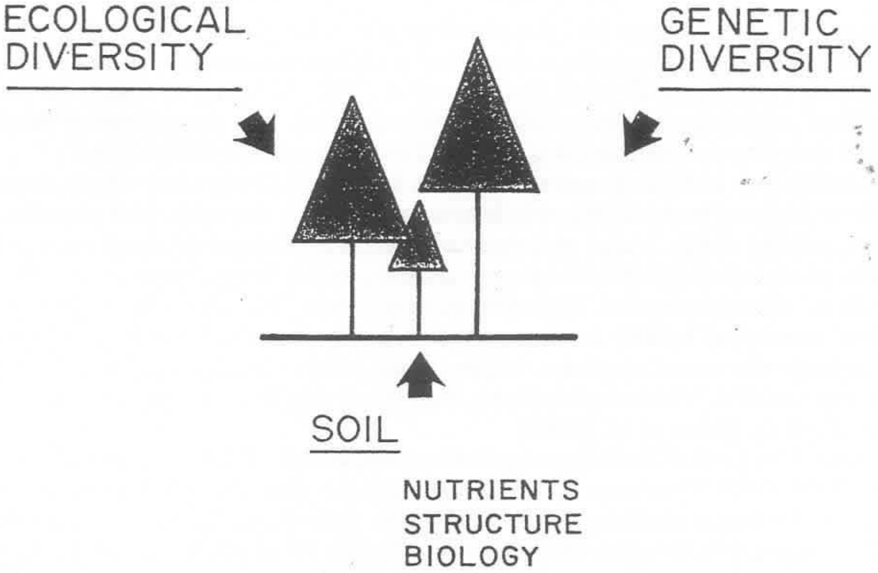

FIG. 6.4. The three legs of sustainable forestry (adapted from Perry 1988).

DIVERSIFICATION—THE NEW IMPERATIVE

How can we retain the natural resilience, assure the potential long-term site productivity of our forest ecosystems? We need to develop strategies which maintain or enhance ecological complexity whenever possible. Such management practices must accommodate early successional species; provide coarse, woody debris; create multistructured and multispecies stands; protect riparian (streamside) habitats; and provide for diverse and functional landscapes.

Accommodating Early Successional Species

We can achieve several ecological objectives when accommodating early successional species. Much of the diversity before the forest canopy closes is associated with weedy generalist plant species but also includes many game birds and mammals. This is also the successional stage during which symbiotic nitrogen-fixing plants, such as alder, ceanothus, and lupine (*Alnus, Ceanothus,* and *Lupinus* spp.), carry on most of their activity. Some relationships may be very complex. For example, mixed stands of ceanothus and Douglas-fir create an environment less favorable for the herbivorous insects feeding on Douglas-fir and for root pathogens (Schowalter 1989).

Silvicultural prescriptions that delay full canopy closure and maintain open forest conditions for long periods include wide spacings in plantings and in early precommercial thinnings. Wide spacings can also reduce planting and thinning costs (Oliver et al. 1986). Furthermore, spacing trials in the region suggest that the economics of growing such stands might suffer very little; although total yields are less, such stands produce trees with larger than average diameters (Reukema 1979, Hoyer and Suanzy 1986).

One such strategy is followed in growing Monterey pine (*Pinus radiata* D. Don) in New Zealand. Stands are precommercially thinned to crop-tree spacing early in stand development (e.g., 9 years). Although of usable size, the thinned material is left as slash because of its marginal economic value. Crop trees are pruned in three stages to produce clear logs. The thinned stands are very open in structure for most of their history and can generate a variety of other products, including forage for domestic animals. Monterey pine is not native to New Zealand; a silvicultural system of this type (i.e., extreme monoculture) would have to be carefully considered when applied to a native species to insure that risks of outbreaks of pests, such as bark and root beetles, were not excessive.

Providing Coarse, Woody Debris

Standing dead trees (snags) and downed logs play a large variety of ecological roles in forests and associated streams and rivers. Ecologically, a dead tree is as important to the forest ecosystem as a live one (Maser and Trappe 1984, Harmon et al. 1986, Franklin et al. 1987, Maser et al. 1988). At the time a tree dies, it has probably fulfilled only about half of its "life" in the ecosystem. The importance of dead wood, especially snags, for wildlife has long been recognized (e.g., Brown 1985). As noted by Elton (1966), ". . . dying and dead wood provides one of the two or three greatest resources for animal species in a natural forest . . . if fallen timber and slightly decayed trees are removed the whole system is gravely impoverished of perhaps more than a fifth of its fauna." Coarse, woody debris is also an important component in nutrient and energy flows, as a source of soil organic matter, as a site for asymbiotic nitrogen fixation, and in erosion control. In waterways, logjams dissipate energy to reduce channel erosion. Logs also provide major structures for retaining food and sediments in stream reaches serving as habitat for an array of organisms, including fish. Additional functions for woody debris exist in large rivers and estuaries, where debris influences channel formation, and even in open ocean and deep marine regions, where it provides a food or energy base for marine organisms; some of these functions are described in Maser et al. (1988).

Nature provides for substantial amounts of coarse, woody debris at all successional stages in unmanaged forests (Spies et al. 1988). However, assuring a continuous flow of such material in managed stands, spatially and temporally, is a major challenge to silviculturists. Woody structures are transient and require constant replacement. For example, Douglas-fir snags in the Pacific Northwest rarely persist in forms useful to animals that create and utilize cavities beyond 60 or 70 years (Cline et al. 1980, Graham 1982).

Therefore, managers must plan to preserve existing coarse, woody debris and to assure future sources (essentially to create new material). Preservation can be greatly aided by modifying or eliminating YUM and PUM practices. Existing snags may be retained in many situations (Fig. 6.5). Creation of new material is probably a more effective strategy than preservation, however, because of the transient nature of wood structures. Green trees of various ages can be retained as sources of future snags and downed woody debris on cutover areas; by spacing mortality of these trees over the rotation, silviculturists can assure a continuing supply of woody debris in varying stages of decay.

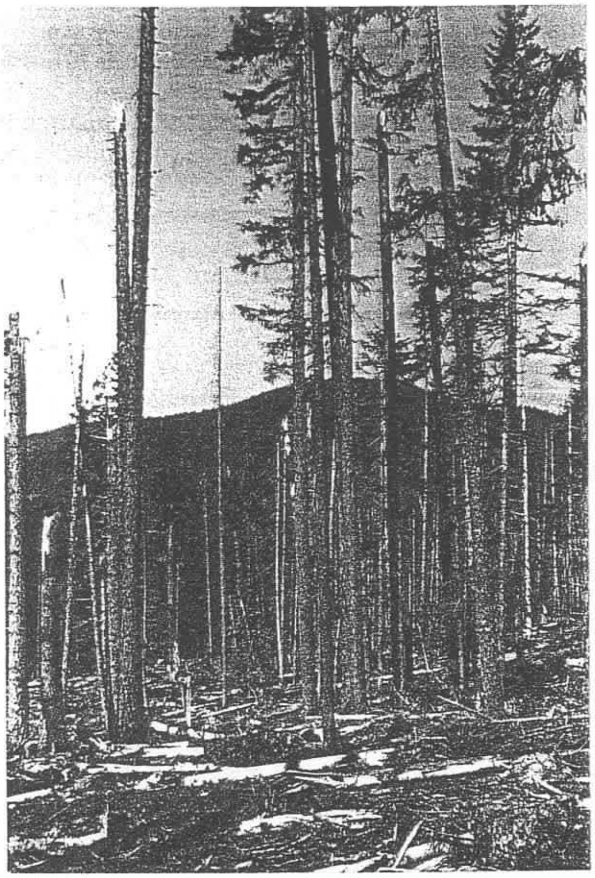

FIG. 6.5. Silviculturists can provide for snags in managed stands by retaining existing snags as well as green trees that will become snags, as has been done on this clearcut on the Willamette National Forest, Oregon.

Creating Mixed Stands

Stands of mixed composition, structure, or both promote ecological diversity, but foresters often avoid planning for such stands because it is simpler not to do so and because timber production objectives have not required it. However, benefits such as improved soil fertility and reduced susceptibility to pests can accrue from mixed stands. Indeed, mixed stands may sometimes produce greater total yields.

Incorporating hardwood species into mixed stands is one major way to retain ecological diversity. Hardwoods can contribute substantially to improved soil fertility: both chemical and physical properties are generally enhanced. Most deciduous hardwoods produce a base-rich litter and mull-type humus. Nitrogen-fixing alders make an additional contribution, although increased soil acidity and lower base saturation may be an undesired consequence (Franklin et al. 1968). Deciduous hardwoods also produce an open canopy for part of the year, creating diversity in environmental conditions in and on the forest floor; shifts in animal populations as well as more rapid carbon and nutrient cycling are probable responses to the increased insolation (Seastedt and Crossley 1981). The hardwood trees themselves offer a very different habitat for epiphytes such as mosses and lichens and for animals large and small. Bigleaf maple (*Acer macrophyllum* Pursh) is, for example, an outstanding substrate for development of epiphytic plants (Coleman et al. 1956).

Use of a greater variety of coniferous species could also enhance soil conditions and increase diversity of live and dead tree structures. For example, cedars and related species (Cupressaceae and Taxodiaceae) are calcium accumulators (Zinke and Crocker 1962, Kilsgaard et al. 1987). Their litter contributes to development of soils richer in bases, lower in acids, and generally more favorable to biological productivity (see, e.g., Alban 1969, Turner and Franz 1985). Because they also produce high-quality wood products, it is somewhat surprising that these species have not been incorporated into more managed stands.

Stands of mixed structure could take many forms and might have many objectives. Classical uneven-aged stands would fall into this category. A simple and broadly relevant example of such a mixed stand would be a two-layered forest comprising two distinct age classes, perhaps created by a shelterwood-type cutting in which the "leave" trees were allowed to remain through the entire next rotation. This approach might be taken to create greater canopy diversity (perhaps for wildlife or moisture condensation purposes), to provide a source of coarse, woody debris, or to produce high-quality wood. Experimental stands of this type have already been created in the Douglas-fir Region (Fig. 6.6).

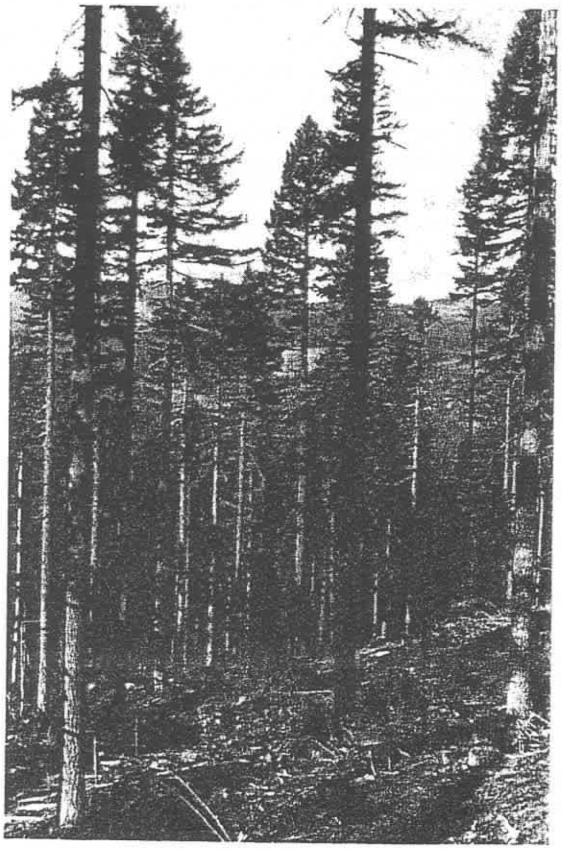

FIG. 6.6. Cutover area on which dominant trees have been left for the next rotation to provide a stand of mixed structure; Douglas-fir on the Willamette National Forest, Oregon.

Protecting Riparian Habitats

Managers of riparian habitats should conserve as much as possible of the rich structural and compositional diversity found in streamside areas (Fig. 6.7). The number and complexity of forest and stream linkages are great. The forest controls the environment (light, temperature, nutrient regimes), provides the food or energy base, and creates the physical structure for small- to medium-sized streams (Gregory et al. 1989).

In forests, the most obvious linkage between a riparian stand and the stream is shading. In-stream photosynthesis and stream temperature are directly regulated by the amount of sunlight received (Minshall et al. 1983, Beschta et al. 1987); therefore, the height, density, and character of the foliage (evergreen or deciduous) determine the light regime. This linkage is tightest along small streams and decreases in proportion to the ratio of vegetation height to width of stream channel.

Riparian stands also function as a nutrient filter between terrestrial and aquatic systems, capturing some of the nutrients moving in the soil solution from the uplands to the stream and adding nutrients through litterfall. Our understanding of the processes of nutrient capture by riparian vegetation is currently rudimentary (Correll 1986), but we do know that riparian plant species differ considerably among themselves in rooting habits and phenology. Consequently, it is probable that a riparian zone consisting of a mixture of species and communities will be more effective than a monotypic stand in capturing and retaining nutrients.

Litterfall, from leaves to logs, is a major transfer of nutrients and carbon (energy) from the terrestrial to the aquatic system. These "allochthonous" inputs (materials from outside the aquatic ecosystem) are the primary energy source for small, heavily shaded streams. Plant species differ considerably in the quality of their leaves and the rate at which the leaves are processed by aquatic organisms (Webster and Benfield 1986), as well as in the timing of leaf fall to the stream (Campbell and Franklin 1979). In addition, plant communities can differ greatly in the total amounts of leaf material delivered to the stream. Land managers can make decisions to create or maintain specific conditions in riparian communities on the basis of the amount and quality of leaf material, and timing of leaf fall (Gregory et al. 1989). For example, if a manager opts for as rich a mix of riparian vegetation as possible to maximize diversity and maintain options, then the simplest management decision might be to stay out of late mature and old-growth areas immediately adjacent to streams; such areas have been found to have a rich diversity of allochthonous inputs relative to recent clearcuts and (especially) young coniferous stands.

The large litterfall component—coarse, woody debris—performs many functions in the stream ecosystem (Harmon et al. 1986), including improvement of fish habitat (Bisson et al. 1987). But amounts of coarse, woody debris have been drastically reduced in most managed areas (Sedell and Swanson 1984). It seems clear that in order to maintain the productivity of the streams flowing through forested landscapes, the land manager must ensure a continuing source of large dead wood; small pieces of wood simply do not have the necessary stability during high flows. This means that large trees must be left in riparian stands being harvested for the first time and that special consideration must be given to rapid regrowth of large trees on already logged lands. The area required to assure appropriate supplies of coarse, woody debris need not be terribly large; for example, McDade et al. (1989) found that 90% of all such material originated within 30 m of the stream.

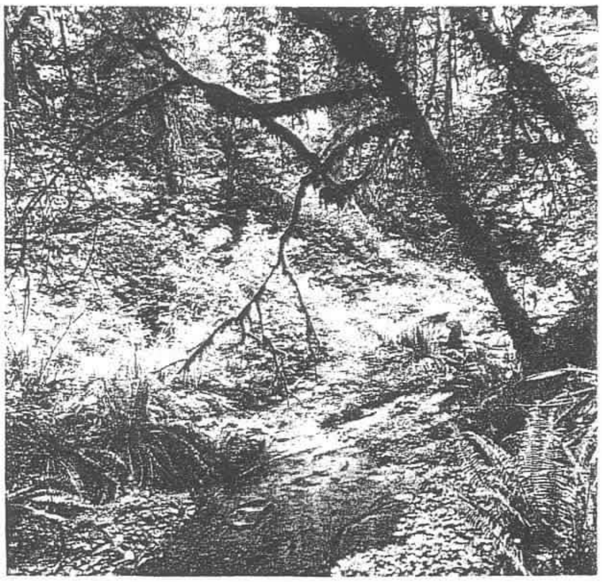

FIG. 6.7. Streamside (riparian) zones such as that at Cherry Creek Research Natural Area, Oregon, are rich in structural, compositional, and functional diversity; management strategies should aim at retaining this complexity to maintain the productivity of aquatic environments.

Providing for Diverse and Functional Landscapes

Land managers must become much more aware of landscape-level needs and effects. We have tended to focus on individual stands and stream reaches without fully appreciating the ways in which all the pieces fit together. The increased concerns with cumulative effects and related issues indicate an increased recognition of landscape-level concerns.

Retaining patches of old-growth forest in managed landscapes is one way to promote diversity. Such patches provide habitat not only for dependent wildlife species, but also for insect predators. A recent survey has shown a much greater diversity and higher numbers of insect predators and parasites in old-growth forests than in adjacent Douglas-fir plantations (see Table 6.1); conversely, numbers of herbivorous insects, especially aphids, were much higher in the plantations, in part because of the abundance and proximity of young succulent shoots (Schowalter 1989). Old-growth forests retain snow in amounts and patterns that are dramatically different from those in clearcut areas; smaller snowpacks and a protected environment in old-growth forests reduce the potential contribution to winter floods, especially where a warm, intense rainstorm melts much of an existing snowpack (Harr 1986). Old-growth forests are also especially effective at scavenging atmospheric moisture and converting it to fog drip because of their high leaf areas (Harr 1982).

The pattern of cutting also affects the way the landscape functions as a whole. Clearcutting in dispersed patches fragments the forest landscape early in a cutting cycle, increases the potential for catastrophic events such as windthrow and wildfire, and rapidly reduces habitat suitable for interior forest species (Fig. 6.8) (Franklin and Forman 1987). Pattern and size of cut areas should be evaluated from the standpoint of multiple resource values and potential risks. Prescriptions should be flexible enough to fit the features and phenomena of the landscape, the nature of the resource, and management objectives. Aggregating, rather than dispersing, cutting activities may also prove desirable economically. It is essential that managers retain greater structural diversity (e.g., green trees and coarse, woody debris) if larger areas are cut over.

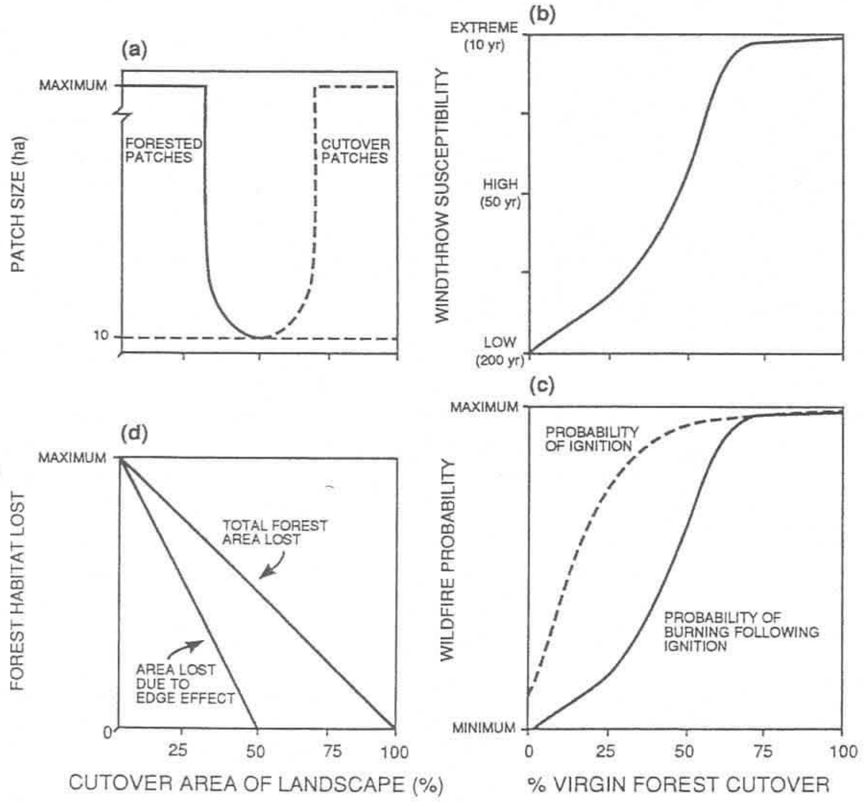

FIG. 6.8. Dispersed patch clearcutting leads to (clockwise): (a) rapid fragmentation of forests, increased susceptibility to catastrophic events such as (b) windthrow and (c) wildfire, and (d) rapid loss of habitat for interior forest species (adapted from Franklin and Forman 1987). Note in (d) that the patches of forest created when about 50% of the area is cut over lose all interior habitat because the patches are so small as to be all edge ("edge effect").

CONCLUSIONS

Forestry in the Pacific Northwest is at a unique stage in development—a stage that calls for the lessons only recently learned to be applied through practices that conserve and even enhance ecological diversity. We in forestry have tended to follow a technical heritage that emphasizes symmetry, order, cleanliness, and efficiency. Evidence is rapidly mounting that we must now foster something of a new tradition which accepts a little disorder or chaos as part of the natural order of things.

Achieving long-term site productivity is a much broader matter than simply maintaining fertile soils. It requires that resilience be maintained throughout forest ecosystems so they can absorb stresses. Ecological complexity is the key to such resilience, just as it is one of the keys to maintaining soil fertility. Thus, foresters should avoid simplifying ecosystems whenever possible—that is, they should "save all the parts to keep future options open."

Forest landscapes are under constant assault by management practices and other human impacts, local to global, planned to unforeseen. To combat uncertainty, we must retain as much ecological margin as possible.

QUESTIONS FROM THE SYMPOSIUM FLOOR

Q: What harvest system would you replace dispersed patch cutting with? Would you, for instance, advocate fewer, but larger cutting units?

A: One alternative to dispersed patch cutting is aggregating cutting areas, i.e., cutting new areas next to existing units, rather than skipping over areas of green forest. Aggregating cuttings in this way can reduce the amount of edge and maximize the size of residual forest islands.

Q: Do you feel the maintenance of ecological diversity is a technical, social/political, or forestry decision? How can we assure this diversity 200 years from now?

A: Basically, the decision to maintain ecological diversity is a societal decision. Resource managers, including foresters, are the technical personnel who will implement society's decision. To assure diversity in the future, society must develop both a national and an international commitment, in conjunction with generating the knowledge base and financial resources needed to support that commitment.

Q: Would you give us a few examples of where simplification has led to management disasters?

A: The recent bark beetle epidemics in the extensive young forests of southern pines probably fall into the category of a management disaster. That is, foresters contributed significantly to the problem through their decisions. The problem with spruce budworm in spruce-fir forests in Maine and southeastern Canada may be another example.

Q: My reading of the scientific evidence is that both simple and complex forest ecosystems can be equally stable. Can you give any proof, other than opinion, to support your argument that ecological diversity improves ecological stability in forest ecosystems?

A: Much of the debate about the relation between diversity and stability has been based upon simple mathematical models and not on experimentation or empirical study. The relationship has been neither proved nor disproved by theoretical ecologists. Back in the real world, however, common sense and empirical evidence clearly show that forest ecosystems which have redundancy in structure and function are more likely to be able to absorb stresses, including species losses, without catastrophic damage to the forest. For example, a stand composed of several tree species is less likely to experience 100% loss of the overstory to a pest or pathogen than one composed of a single species. Engineers recognize the value of redundancy in their work (e.g., as in aircraft), and it is an even more appropriate strategy in the art of ecological engineering known as forestry.

Q: Others have suggested using low-elevation, less productive farm land for intensive, short forest rotations and using upper elevation, steeper slopes for minimally managed and much longer rotations. What is your view on this?

A: Converting marginal agricultural lands to the structurally more complex ecosystems known as forests seems like a sound idea—such could provide wood fiber, wildlife habitat, and a variety of other "products." Moreover, including these marginal farm lands into the forest land base could reduce the pressures for intensive management of more fragile upper slope stands (see chapter 8, this volume).

Q: Would uneven-aged management be better for the Douglas-fir Region than clearcutting? Would it allow more management options for ecological diversity and resilience?

A: Some alternative to the current even-aged emphasis would probably allow for many more management options, but I am reluctant to refer to it as uneven-aged management. That suggests selective cutting systems, which I believe have a limited role in the Region. Unfortunately, the broad spectrum of possible cutting methods is not described in textbooks or taught in most silviculture courses. In this chapter, we mention one type of alternative scheme, in which a stand of various age classes is created by allowing selected green trees to remain at the time of harvest for one or more subsequent rotations. I believe the future of silviculture, at least on public lands, lies in this middle ground between clearcutting, on the one hand, and selection systems, on the other.

Q: What is your opinion of forest management policies recommending leaving 2 or more wildlife trees per acre in clearcuts?

A: I favor it. It is a start on developing practices which retain more structural (and, thereby, ecological) diversity on cutover lands.

Q: Are YUM and PUM totally negative when they replace burning, which often reduces genetic and species diversity and also removes dead wood?

A: Of course there are trade-offs between YUM and slash burning. However, light and medium, rather than heavy, fuels are typically the primary objective of broadcast slash burning, so one practice generally does not replace the other. If I had to choose one practice over the other, I would probably prefer burning because tends to leave much more of the large woody debris than YUM. Overall, YUM and PUM remove, at substantial cost, structures which should remain on site to enhance long-term productivity and provide animal habitat.

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